TECHNICAL REPORT
Contract #: N00014-94-C-0216
Item #: 0001AA

ERBIUM DOPED SILICON LEDs USING IC COMPATIBLE PROCESSING

Submitted To:
Office of Naval Research
Code 251B KIJ
Ballston Tower One
800 North Quincy Street
Arlington, VA 22217-5660

Submitted By:
Implant Sciences Corporation
107 Audubon Road
#5 Corporate Place
Wakefield, MA 01880

1.0 Introduction

The purpose of this program is to demonstrate the capability of the IC compatible process technology of rare earth ion implantation for the integration of photonic interconnection with silicon based electronics. As microchip technology pushes packing density, speed and power requirements ever higher, interconnects are getting smaller and more closely spaced. Design parameters and therefore performance characteristics are presently limited by the power dissipation, bandwidth, interconnection (pin-out) density, and reliability constraints of aluminum interconnects such as electromigration and stress migration. The most appropriate solution is to employ erbium doped silicon light emitters, silicon based waveguides, and silicon based detectors to provide an IC compatible process technology.

2.0 Work Accomplished

A proprietary ion source was fabricated and assembled using a second generation design incorporating improvements learned from previous non-SBIR, government funded research into ion implanted rare earth thin film electroluminescent displays. The source was optimized for erbium generation. It was eventually discovered that more than adequate beam current could be generated to perform the low dose implants, but cleanliness of the spectra was in question. Stainless steel heat shields and the gas feed line contributed unwanted contaminant peaks to the spectra. Fe-54 in particular, lay directly under the Er^{+++} peak. However, the singly and doubly charged implants could be performed to collect annealing data. At the time of this writing the source was being further improved by eliminating much of the stainless steel in the source and using high temperature metals whose constituent peaks lie away from any Er peaks.

All of the implants performed were modeled using Profile Code™, a commercially available software package which models implant depth distributions, to determine the planar Er dose which yields the desired atomic concentration. Co-dopant implant energy was determined in the same manner so that the Er and co-dopant peaks were coincident. For the anneal studies a matrix of 3 Er implant energies (depths) by 6 co-dopant species at 2 Er: co-dopant dose ratios annealed at 3 temperatures for 3 time durations was performed. Erbium Implants were performed at 200 and 400 keV, (the 600 keV implants will be completed after the source modifications mentioned above are completed) yielding an atomic concentration in silicon of 5.00E17/cm^3. Fluorine, chlorine, oxygen, selenium, nitrogen, and carbon were implanted as co-dopants to provide a ligand field to enhance emission to atomic concentrations of 1.00 and 2.00 E18/cm^3. An example of the distribution predicted by Profile Code for 400 keV Er and O at a 2:1 concentration ratio is given in Fig. 1.

Erbium luminescence in silicon depends strongly on the annealing conditions as has been shown in earlier work at MIT on deep erbium implants ($\sim 1.5\mu m$) in silicon. Therefore the major task in the first step of this program is to determine optimal annealing conditions. The annealing conditions for deep implants are not directly transferable since a different kind of damage is produced while performing the shallow implants.

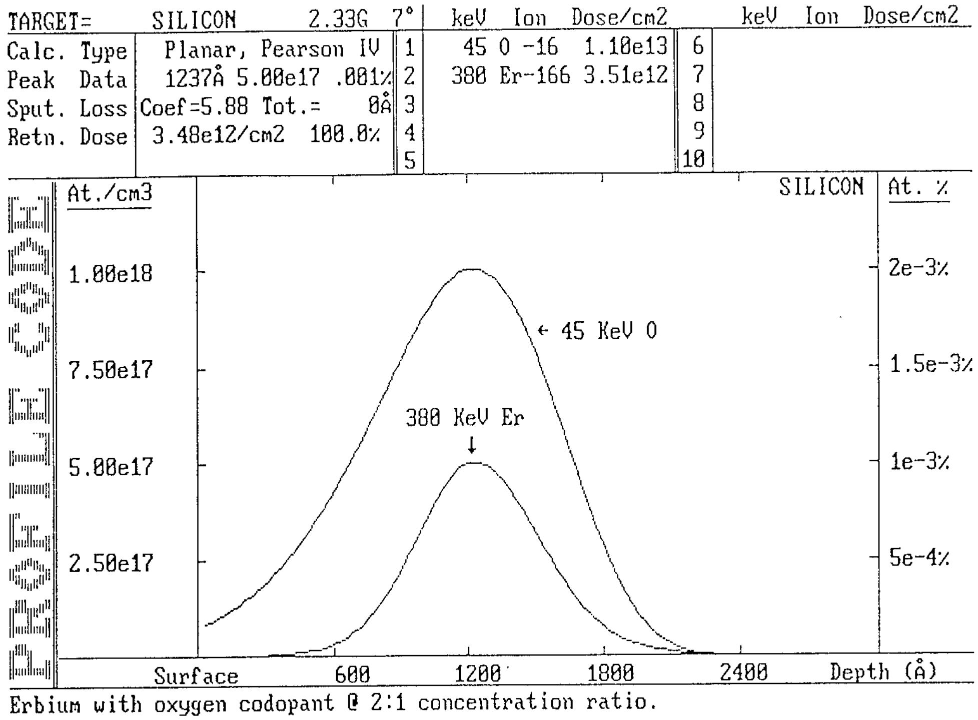

FIGURE 1 Profile Code distribution for Er and O. O^+ implanted at 45 keV will fill the same volume as Er.

A second variable in the experiments is the co-implant. Earlier measurements showed that erbium, co-implanted with elements like N, F, C or O produced several orders more light intensity compared to erbium in float zoned (FZ) silicon. For the annealing studies performed Czocharlski (Cz) wafers were used.

The samples were furnace annealed at 800, 900 and 1000° C for 10, 20 and 30 minutes. All samples were measured by photoluminescence spectroscopy (PL) at 4.2 K. The results of the erbium emission for samples annealed at 800 and 900° C for 30 min. are shown in Fig. 2. These annealing conditions produced the highest PL intensities. The PL intensities for samples annealed for shorter periods of time or at higher temperatures were significantly smaller. The highest emission intensity at 800° C for an O co-implant of 2.0 E18/cm^3 is comparable to the intensities measured for high energy implants. None of the other co-implants showed any improvement in the PL intensity. At 900° C a carbon co-implanted sample showed the highest PL intensity.

SIMS measurements of F co-implanted and annealed samples revealed that F out-diffuses during the annealing process. This behavior was observed after a 60 sec. rapid thermal anneal (RTA) at 900° C. Out-diffusion is a possible explanation for the low PL intensity of C, N and F co-implanted samples. The SIMS data for this system have been incorporated into Profile Code so that the F peak can be placed just slightly deeper than the Er peak in subsequent implants.

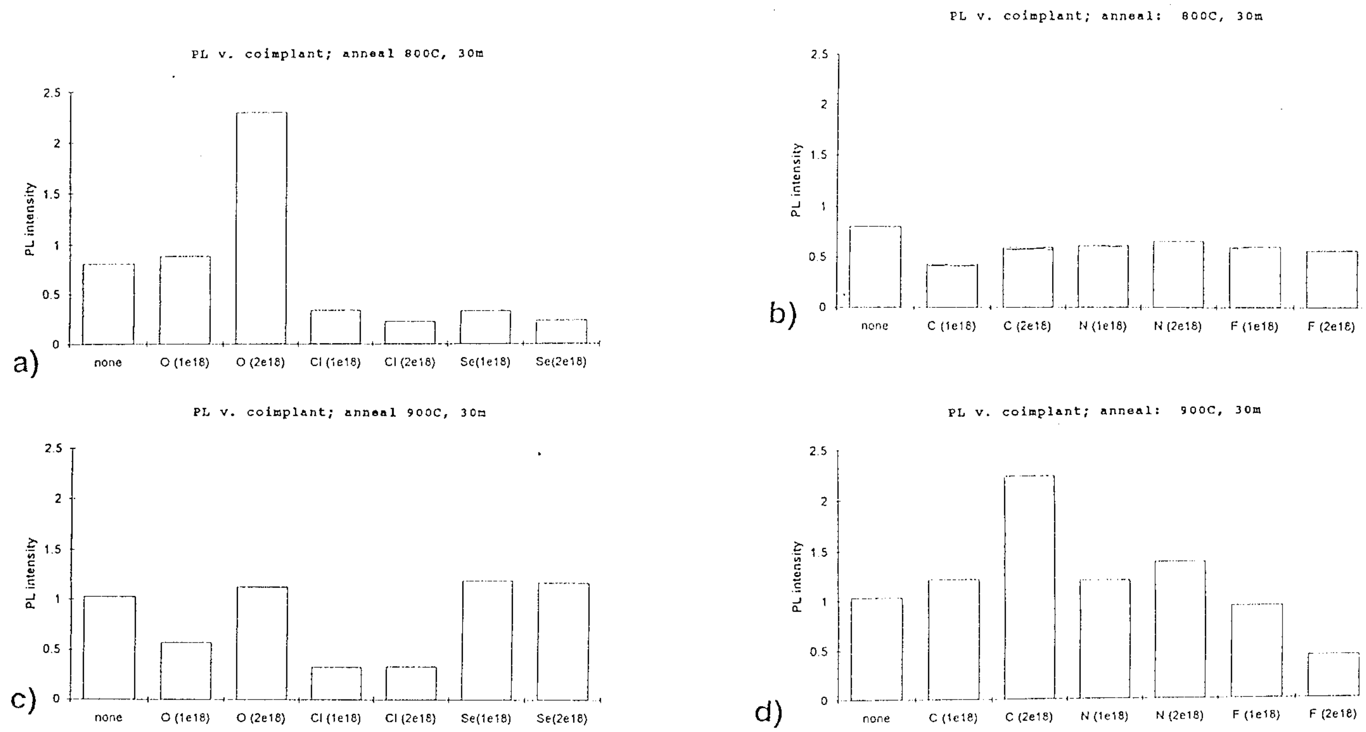

FIGURE 2 Photoluminescence results for 30 minute anneals at 800 and 900° C.

The PL intensity at elevated temperatures is critical for device applications and therefore the choice of co-implants and annealing conditions must be optimized to yield the highest output at relatively high temperatures. To evaluate the high temperature performance of the samples the PL intensity at 200K was measured. The samples with the best high temperature performance are shown in Fig. 3. The O (2×10^{18} cm^{-3}, 800° C, 30 min.) co-implanted samples exhibits the strongest PL emission at room temperature observed up to date. The Se co-implanted sample shows significant high temperature performance and in light of the relatively weak low temperature emission, (Fig. 2a) could be potentially enhanced by at least a factor of 4.

Based on these findings the first LED devices were designed. These LED's will be co-implanted with O at 2×10^{18} cm^{-3} and are currently in process at ISC. The possibility of rapid thermal annealing (RTA) is currently being evaluated. These anneals are much shorter durations than furnace anneals and are expected to greatly reduce out-diffusion of the co-implants.

3.0 Work to be Performed in the Following Reporting Period

- Modifications to the source will be completed.

- The 600 keV implant and co-dopant set will be completed and annealed.

- MIT will provide substrates for implant which will be patterned and fabricated into LED's.

- Additional Er/co-dopant combinations will be considered.

- Fabricated devices will be characterized.

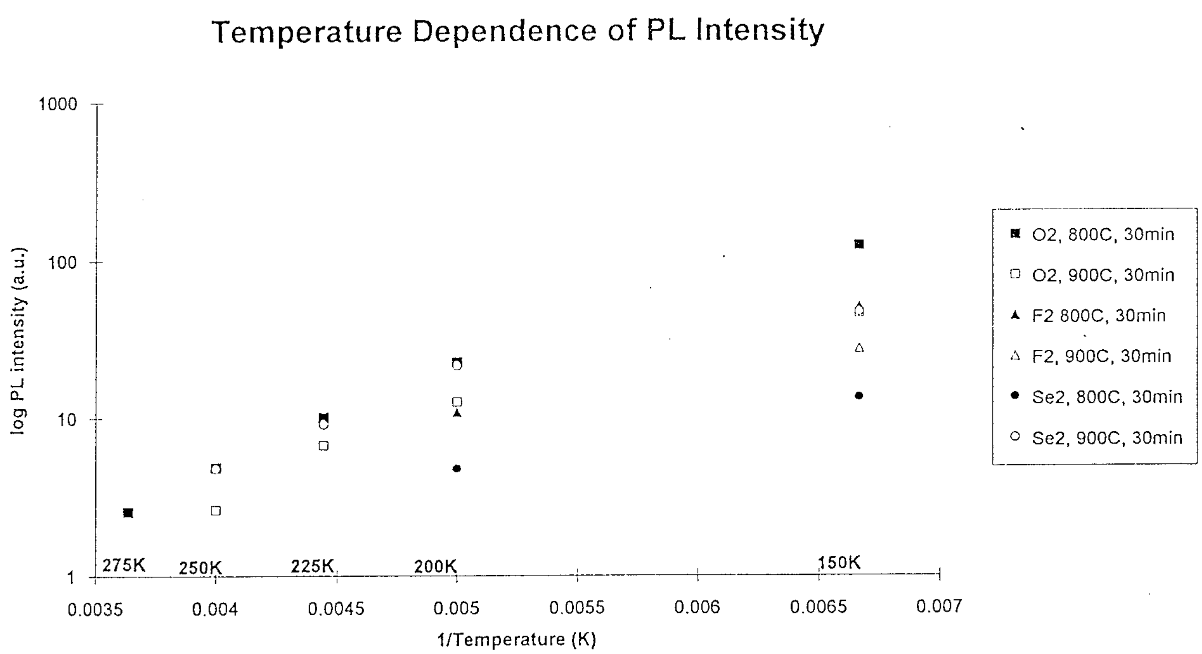

FIGURE 3 Summary of results for the samples exhibiting the best high temperature performance.